MECHANICAL CHARACTERISTICS ANALSIS OF PAVEMENT IN RESIDENTIAL SITES

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ABSTRACT

With rapid industrialization and urbanization, an increment of road pavement which takes the most part of the impermeable surface causes rapid drainage of rainfall, resulting in floods in urban areas. Reduced permeation of rain leads to the imbalance of the ecosystem, such as low subterranean water levels and dried water, and is pointed out as the main cause of environmental problems such as the heat island phenomenon. Recent development of pavement technology, e.g., permeable pavement, aims to reduce environmental load, while providing the basic functions such as driving stability and comfort. The pavement technologies under the development which may reduce the environmental load are mostly centered on functionality, and therefore, have limits to fundamentally solve the water circulation problem on pavement.

This study aims to review the mechanical characteristics of pavement in residential sites and to propose the optimum section of the pavement with high water circulation, which would reduce the environmental effect on pavement.

1. INTRODUCTION

Korea's rapid economic growth in the 1970s resulted in urbanization in many areas. In order to expand the infrastructure in these new urban areas, asphalt pavements have been made. The asphalt-paved roads result in the rapid increase of impermeable pavements in urban areas, which, in turn, causes the heat island phenomenon and reduces infiltration and instant storage of rainfall. The asphalt pavement is pointed out as the reason for urban flooding and low subterranean water levels caused by a rapid discharge of rainwater. Therefore, in the asphalt pavement field, studies on

permeable pavement technology are under way to prevent destruction of the natural water circulation system caused by asphalt pavement. The current studies on permeable pavement are centered on the verification of hydrological effect of the permeable pavement technology. Permeation of rain through road may weaken the roads, and these structural limits of permeable pavement result in the limits of the work

area.

This study aims to provide the base for application of permeable pavement to reduce the impermeable pavement in residential sites. For this purpose, this study has analyzed the mechanical behavioral characteristics of permeable pavement against the weakened bearing force on the road where rain water infiltrates into subterranean areas, and also proposed the method of application of permeable pavement to roadways.

2. ROAD PAVEMENT AND WATER CIRCULATION SYSTEM

This chapter compares the water circulation system in urban areas with the natural water circulation system, and considers the pavement technology to improve the water circulation system in urban areas, its application and cases.

2.1 Water circulation system

“Water circulation” indicates a series of processes in which rain permeates into the ground, flows to storages or streams, to the sea, and evaporates. In the natural water circulation system, no rapid discharge of rainwater occurs thanks to natural greens. However, rapid industrialization and economic growth have accelerated pavement establishment in urban areas, causing rapid increase of impermeable pavement surface. The impermeable pavement skips permeation of rainfall into the ground and storages from the water circulation system, causing a rapid discharge of rainwater (Figure 1). It also results in flood damage in urban areas.

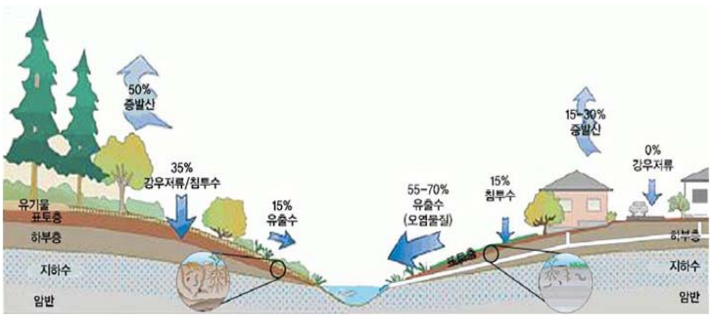

Figure 1. Water Circulation System between Nature and Urban Area

2.2 Pavement technologies to improve the water circulation system

In general asphalt pavement, due to the impermeability of the pavement materials, rainfall is treated with side drainage facilities along the surface of pavement with the road grade. The permeable pavement, however, allows permeation of rainfall into the lower layer of the pavement structure through the openings of the pavement, solving the problems caused by increased impermeable pavement in urban areas (Figure 2).

The permeable pavement technology uses the permeability of the pavement structure to discharge

rainwater, rather than using the surface of the impermeable pavement. The permeable asphalt pavement allows permeation of rainwater into the surface and the boundary layer. The impermeable material is used for the lower part of the subbase, and rainwater is treated by the side drainage facilities.

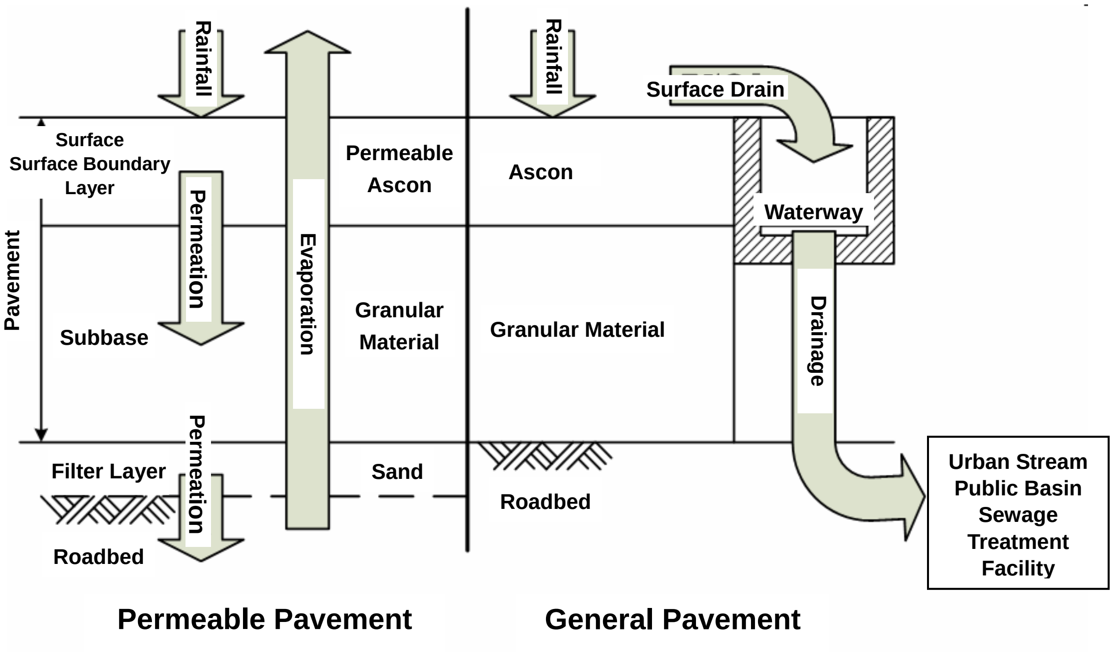

Figure 2. Comparison of Structure between General Pavement and Permeable Pavement

3. TREND AND EFFECT OF STUDIES ON PERMEABLE PAVEMENT

3.1 Trend of domestic/overseas studies on permeable pavement

It was not until recently that they began to recognize the environmental problems caused by impermeable pavement and attempt the efforts to solve these problems in Korea. In order to improve the water circulation system in urban areas, permeable pavement is applied to light transportation areas such as footpaths and parking lots. Studies on hydrological effects are also under way. The permeable pavement has been applied since the 1970s in some overseas countries. In Japan and Europe, the technology was first applied to footpaths, and then, extended to parking lots and light traffic roads. Since the late 1990, studies on permeable pavement for roadways have been under way.

3.2 Hydrological effect of permeable pavement

3.2.1 Hydrological effect of permeable pavement in Korea

The hydraulic model experiment on the hydrological effect of permeable pavement on roadways to the water circulation system showed that it reduces discharge of rainfall. Jae-Eung Lee et al. tested

the effect of permeable pavement to reduce discharge of rainwater, and the effect when it is applied to urban areas. They measured the discharge of rainfall between the impermeable pavement material with the permeable material of 20cm / 80cm depth, and compared and analyzed the permeated amount of each material and the effect of rainwater discharge reduction. The measurement through the model experiment showed, under the assumption that there has been no preceding rain, that the 80cm-thick permeable pavement material allows permeation of nearly whole amount of rainwater if rain at 150mm/h continues for 30, 60 and 120 minutes. The 20cm-thick permeable pavement showed reduction of discharge of surface water by approx. 81%, 32% and 28%, respectively [1].

Jeong-Min Lee et al. analyzed the effect of the permeable pavement on increase of water flow in a watercourse through an SWMM (Storm Water Method Model) at the Hakeui stream, a branch of the Anyang stream. If 10% of the impermeable area of the Hakeui stream is replaced by the permeable pavement, the water flow at the Bisan bridge in the lower part of the Hakeui stream is reduced by 1.25-8.36m^3/s during the rainy seasons, and is increased by 0.03-0.07m^3/s during the dry season. When comparing surface water, if 10% of the impermeable area is replaced by the permeable pavement, the pondage and the minimum flow would increase by 3% and 17%, respectively [2].

3.2.2 Hydrological effect of permeable pavement in overseas cases

The Haero stream area in Japan, which had been urbanized rapidly since mid 1950s, had suffered frequent urban floods due to reduced permeability and maintenance capability. Increased pollutants had caused deterioration of water quality in the stream. In order to solve these problems, they established the water circulation regeneration measures. The water circulation analysis showed that, among others, the permeable pavement was the most effective measure. It was analyzed that the permeable pavement reduced the surface discharge by at least 70mm, and increased permeability into subterranean area by at least 80mm. The ground water discharge which forms the base flow of a stream is increased by approx. 20mm, which results in increase of base flow by approx. 10% in average. Michele C. Adams reported that the permeability according to the status of soil under stormwater can be maximized through appropriate construction work and management, and that the water storage capability of the permeable pavement can prevent disasters (Figure 3).

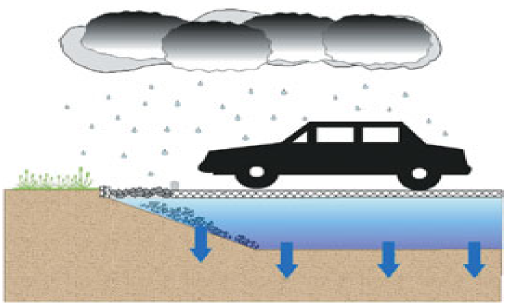

Figure 3. Water Storage Effect of Permeable Pavement

3.2.3 Mechanical characteristics of permeable pavement

Permeable pavement is applied to the roads of light traffic load, such as parking lots and footpaths. This is because of the structural problems of permeable pavement, such as weakened roadbeds caused by permeation of rainwater into the lower layer. As mentioned above, these studies of both domestic and overseas are centered on verification of hydrological effect of the permeable pavement technology, and only a few of them aim at the expansion of area to which the permeable pavement is applied. Therefore, in order to apply the permeable pavement to improve the water circulation system, it is considered necessary to perform studies to secure durability and to verify the water circulation improvement effect.

3.3 Characteristics of behavior of roadbed in relation with water

The permeable pavement allows rainwater into the roadbed at the bottom layer of the pavement structure, and, there can be a structural problem such as weakening of roadbed under the effect of rainwater. Therefore, this technology has been applied to the section with low traffic load, such as footpaths and parking lots. In order to apply the permeable pavement technology to roadways, it is required to understand the effect of the mechanical characteristics of roadbed changed by permeation of rainwater on the stability of the pavement structure.

Gil-Cheol Kwon et al. has reported, in the study on the change of dynamic properties of Korean roadbed soil sample according to the soil moisture percentage, that, under the optimum moisture percentage and the moisture percentage equals to the optimum moisture percentage ±2% of the samples formed in the same dry weight, the maximum shear modulus of elasticity grows as the restricted stress and the soil moisture percentage grows, and that the normalized modulus of elasticity reduction curve is not much influenced by the soil moisture percentage [3].

The technology lab of Japanese Road Inc. reported, in its study of roadbed bearing power on sites, that the deflection of FWD grows at the point in which the roadbed soil moisture percentage grows after rainfall, but that no change in the modulus of elasticity of the roadbed is deduced from this result [4].

Various indoor studies performed in Korea and overseas countries show that the bearing force of roadbed reduces as the soil moisture percentage grows, but that the influence to the bearing force of roadbed becomes insignificant according to the thickness of the asphalt pavement and if a drainage layer or filter layer is installed.

4. CHARACTERISTICS OF MECHANICAL BEHAVIOR OF PERMEABLE PAVEMENT

Because rainwater directly permeates into the roadbed through the pavement, the permeable pavement might weaken the roadbed. Therefore, it is required to have a sufficient thickness of the pavement layer to secure the structural stability according to the roadbed bearing force, planned

traffic and permeability performance of the roadbed in the permeable pavement section, even if the facilities such as perforated drain pipes or collecting wells, or if the bearing power of the roadbed is deteriorated. Therefore, this section studies the characteristics of mechanical behavior of roadbeds according to the asphalt pavement section and the load conditions in the Gwangju Suwan housing complex on the assumption that the roadbed bearing power is weakened due to permeation of rainwater.

4.1 Finite element analysis section and properties of material

The finite element analysis was made on the dense asphalt pavement section in the Gwangju Suwan housing complex. The permeable pavement section was analyzed through comparison of the roadbed displacement according to the weakened bearing power of the roadbed. According to the execution report of the Gwangju Suwan housing complex land development project, the sectional structure of the asphalt road in the complex is as illustrated in Table 1 [6]. As shown in Table 1, the roads are classified into major roads, wide roads, medium roads and narrow roads based on daily car traffic. Wide roads and medium roads are subdivided based on the traffic. Surface and intermediate layers are separated in general asphalt roads in Korea. However, the modulus of elasticity of the intermediate layer in the asphalt roads in Korea is approx. 90% of the surface, which means that there is no clear distinction between the intermediate layer and the surface [5]. Therefore, in the finite element analysis model, the intermediate layer was included in the surface depth.

Table 2 shows the material properties entered in the finite element analysis. The modulus of elasticity of each layer in Table 2 is the median value of the modulus of elasticity range normally used in asphalt road [6]. The normally used Poisson’s ratio was applied because it has little influence to the finite element analysis of pavement [7].

Table 1. Road Pavement Section in Gwangju Suwan Housing Complex

Layer	Major road (㎝)	Wide road class 1 (㎝)	Wide road class 2 (㎝)	Wide road class 3 (㎝)	Medium road class 2 (㎝)	Medium road class 3 (㎝)	Narrow road (㎝)
Surface	5	5	5	5	5	5	5
Intermediate layer	6	6	6	6	6	6	-
Surface boundary layer	19	18	17	20	12	10	10
Subbase	35	41	37	39	32	29	35
Total thickness	65	70	65	70	55	50	50
Design method	AASHTO	AASHTO	AASHTO	AASHTO	AASHTO	AASHTO	T_A

Table 2. Properties of Materials used in Finite Element Analysis

Layer	Modulus of elasticity (MPa)	Poisson's ratio
Surface	3432	0.30
Surface boundary layer	2157	0.30
Subbase	517	0.35
Roadbed	68	0.40

4.2 Load of finite element analysis model

The load condition of the finite element analysis model for application of permeable pavement in the complex was based on the ground contact pressure, the wheel load given to the pavement surface as shown in Figure 4. The vehicle types operated in the complex is based on the vehicle type classification system for national road specified in the Annual Statistical Report on Road Traffic. Table 3 shows the actual ground contact pressure of typical tire spec of each car type [8].

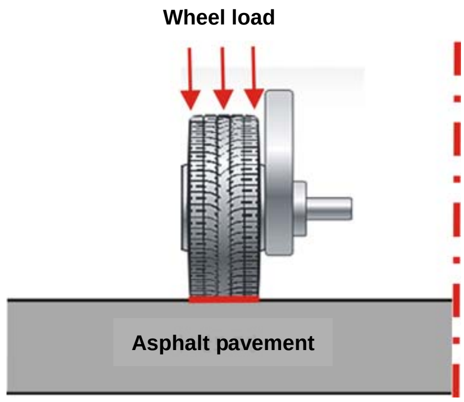

Figure 4. Wheel Load

Table 3. Total Ground Contact Pressure and Area by Car Type

Road Type	Vehicle Class	Representative Tire Spec.	Total Ground Contact Area (㎠)	Total Ground Contact Pressure (㎏/㎠)
Narrow Road	Class 1	195/65R15	243.6	2.55
Medium Road	Class 3	11R22.5-16PR	596	6.44
Wide Road	Class 5	11.00*20-16PR	644	7.10

4.3 Finite element analysis model

Asphalt pavement has infinite size in reality, but it is not possible to create the finite element analysis model of the same size. In order to analyze the element accurately, it is required to model

the tire that meets the asphalt pavement and the asphalt pavement structure, respectively. In this study, however, the model was made for the asphalt pavement model only, skipping the tire model, and the 2D finite element analysis model was used. The size of the finite element analysis model was 250cm x 250cm. The size of the element used for the part on which the ground contract pressure of the tire was 1cm. The element sizes for other parts are selected depending on the level of importance. The ground contact pressure of the tire is placed in the center of the 2D finite element analysis model. For the boundaries of the finite element analysis model, left/right boundary was available for up/down adjustment with left/right restriction, and up/down restriction was applied to the bottom part (Figure 5).

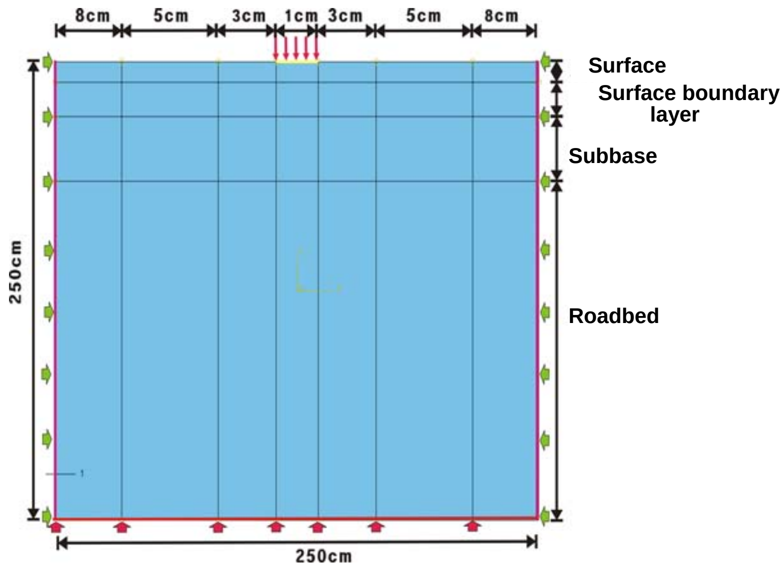

Figure 5. Finite Element Analysis Model

4.4 Results of finite element analysis

4.4.1 Analysis of finite element of general asphalt pavement

Using the sectional structure in the execution design report for Gwangju Suwan housing complex land development project and the 2D analysis model that represents the ground contact pressure and width found through the documents, the maximum displacement at the load point by road types. Table 10 shows the highest displacement in wide road class 2 in the Gwangju Suwan housing complex. This may be because the total pavement depth of the section is thinner than wide road classes 1 and 3 by approx. 5cm. The lowest maximum displacement was measured in wide road class 3 rather than in class 1 with the same pavement thickness, due to the thickness of the surface boundary layer.

Table 10. Maximum Displacement by Load (Unit: mm)

Layer	Major Road	Wide Road Class 1	Wide Road Class 2	Wide Road Class 3	Medium Road Class 2	Medium Road Class 3	Narrow Road
Surface	1.72	1.68	1.73	1.66	1.55	1.61	0.43
Surface boundary layer	1.70	1.66	1.71	1.65	1.53	1.60	0.43
Subbase	1.67	1.63	1.68	1.62	1.51	1.58	0.42
Roadbed	1.57	1.52	1.58	1.51	1.42	1.49	0.39

4.4.2 Analysis of finite element according to reduction of bearing power of roadbed

In order to analyze the effect of weakened roadbeds caused by permeation of rainwater into roadbeds on the permeable pavement roadways, change of roadbed displacement was measured by reducing the roadbed bearing power by up to 20% (at 5% scale) of the modulus of elasticity of the existing section. As the roadbed bearing power reduces, displacement of roadbed increases by approx. 19%.

Table 11. Displacement of Roadbed according to Deterioration of Roadbed Bearing Power

Classification		Deterioration of Roadbed Bearing Power (%)					Increase of Displacement (%)
		0	5	10	15	20	
Surface Displacement (㎜)	Major Road	1.57	1.66	1.74	1.82	1.95	19.03
	Wide Road Class 1	1.52	1.61	1.68	1.76	1.88	19.38
	Wide Road Class 2	1.58	1.67	1.74	1.83	1.95	19.26
	Wide Road Class 3	1.51	1.60	1.67	1.76	1.88	19.42
	Medium Road Class 2	1.42	1.50	1.57	1.64	1.75	18.91
	Medium Road Class 3	1.49	1.58	1.65	1.72	1.84	18.72
	Narrow Road	0.39	0.41	0.43	0.45	0.48	18.56

4.4.3 Durability of permeable pavement

As described above, the roadbed displacement grows as the roadbed bearing power becomes deteriorated. This section suggests the pavement thickness that shows the roadbed displacement of general asphalt pavement despite the deterioration of roadbed bearing power. In this study, only the subbase thickness is considered as the extra pavement thickness (Figure 6).

Figure 6 shows that thickness of subbase grows by up to 32cm in the major road section when the roadbed bearing power is reduced by 20%. Figure 12 shows the relationship between the roadbed bearing power and the extra thickness by road types in Gwangju Suwan complex. Formula 1 is the basic formula for the relationship of subbase extra thickness.

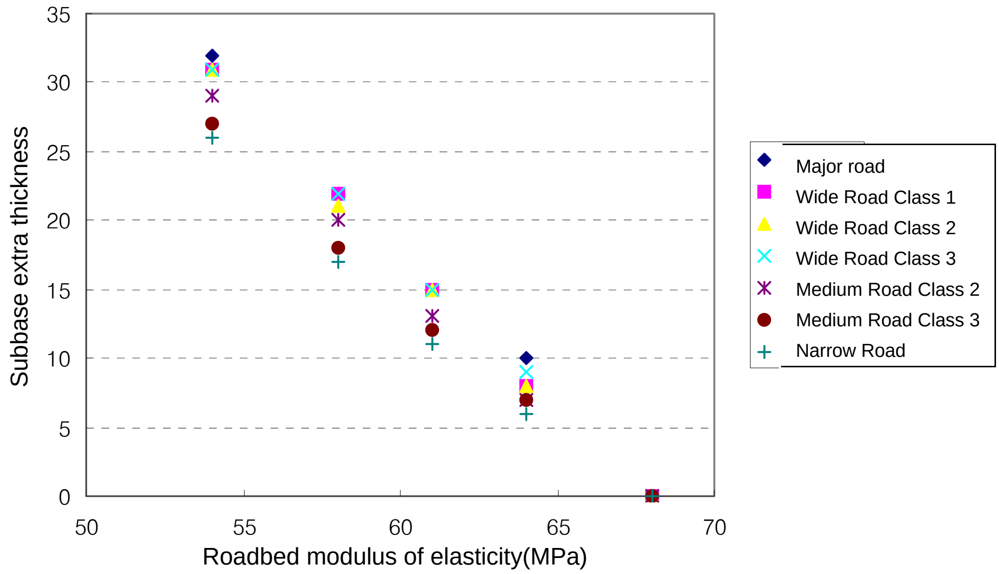

Figure 6. Extra Thickness by Change of Roadbed Bearing Power

Table 12. Regression Equation Elements for Subbase Extra Thickness

Road Class	A	B	R^2
Major Road	-2.2414	152.52	0.9965
Wide Road Class 1	-2.2328	151.40	0.9991
Wide Road Class 2	-2.2069	149.62	0.9982
Wide Road Class 3	-2.2069	150.02	0.9996
Medium Road Class 2	-2.0862	141.06	0.9962
Medium Road Class 3	-1.9138	129.54	0.9955
Narrow Road	-1.8534	125.06	0.9913

Subbase Extra Thickness = $A \times E + B$ Formula 1

where, E: Modulus of elasticity

A,B: Parameters

5. Conclusion

This study is the foundation stage for application of permeable pavement to roadways. In this study, the characteristics of roadbed behavior against water was considered from domestic/overseas documents, and based on these characteristics, the characteristics of roadbed soil behavior in accordance with the deterioration of roadbed bearing power caused by permeation of rainwater.

The characteristics of roadbed soil behavior against water were inconsistent between indoor experiments and site experiments. In indoor experiments, the bearing power of roadbed soil decreases as the soil moisture percentage grows due to the influence of water. In the site experiments, it was found that, despite the growing soil moisture percentage, bearing power of roadbed soil is not affected if the thickness of the pavement is over a certain level, or if the perforated drain pipes are installed with the drainage layer or the filter layer placed on the roadbed.

The finite element analysis according to the sectional structure specified in the execution design report on the Gwangju Suwan housing complex land development project showed the displacement on the roadbed. It was found, in case of Gwangju Suwan complex, that the displacement is highest in the wide road class 2. As the bearing power of the roadbed decreases by 20%, the displacement increases by 19%.

This study proposes the relationship formula on the subbase extra thickness to secure durability against deterioration of roadbeds of the permeable pavement. As the bearing power of the roadbed decreases by 20%, the maximum extra thickness of the subbase is 32cm.

This study analyzes the mechanical characteristics of the permeable pavement as the base study for application of permeable pavement to roadways. In order to apply the permeable pavement to roadways, it is required to study the permeability and conditions of the roadbed and the foundation, and to analyze the planned traffic.

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